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AN ELECTRICAL CONDUCTANCE HAY MOISTURE METER

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SUMMARY

Moisture content is an important factor in preserving the quality of hay during curing and storage. An instrument has been needed for fast and accurate measurement of moisture content. Therefore, an instrument using the electrical conductance principle was constructed and tested.

The instrument measures the moisture content of hay with sufficient accuracy to serve as an important tool during haymaking ($r = 0.94$ for alfalfa). The meter is completely portable, and is powered by two transistor radio-type batteries. A large, representative sample (200 to 250 grams dry matter) requiring no special preparation is subjected to 600 pounds of pressure per square inch for each measurement. Approximately 2 to 3 minutes is required to make the entire moisture determination.

The accuracy of the meter is affected by temperature; a correction factor or compensation is therefore necessary. The instrument was calibrated at a temperature of 75°F. An increase of 1 degree in temperature raises the moisture reading 0.1 percent.

High-moisture hay (above 50 percent) cannot be measured with the procedure described due to removal of juices by the high pressure. To measure high-moisture hay, the meter should be calibrated at lower pressures.

An Electrical Conductance Hay Moisture Meter[1]

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INTRODUCTION

Moisture determinations have always been important in maintaining the quality of forage crops. Once forage is cut, the haymaker's task is to conserve quality. The moisture contents of common types of freshly cut forages range from about 65 to 80 percent. To maintain the nutritive value of the product, the moisture must be reduced to 15 to 20 percent (considered safe for storage) as rapidly as possible. Hay, properly cured and stored, loses nutrients very gradually and remains a dependable feed for a number of years. Hay that is too moist (1)[2] tends to pack, which causes heat and mold damage. Overdried hay tends to shatter its leaves and to be brittle, discolored, and dusty.

Recent developments in harvesting, storage, and preservation of grass and legume hay have increased the need for fast, accurate, simple and versatile methods of moisture determination. For example, moisture content before processing is a critical factor in maintaining the stability of pelleted and wafered forages. Balk (2) states, "Moisture content of the material being processed was found to be the most important factor contributing to fuel and power requirements and to the physical properties of the finished pellets."

The primary purpose of the present research is to develop a fast and accurate objective method to determine the moisture content of hay in the field.

REVIEW OF LITERATURE AND PRESENT METHODS

For many years, hay has been twisted, smelled, rattled, or scratched in an attempt to estimate moisture content. Several instruments and methods have been developed for measuring the moisture content of hay in the field. Parks (9) describes a method using calcium carbide to drive off the moisture. This method has been developed into a commercial unit. Woodward (11) developed a method that pressed the sample to determine the moisture. If juices were expressed from the bales in the press, the moisture was above 68 percent. If no moisture appeared, the sample was claimed to be less than 68 percent. Dexter (3) described a method using the exhaust heat from a car or tractor to dry hay for moisture calculations. Isaacs and Wiant (6) used a method similar to that of Dexter.

Dexter (4, 5) suggests and illustrates possible use of a vapor pressure or relative humidity approach to moisture testing. Isaacs and Wiant (7) describe an electrical resistance method for determining moisture of hay in the windrow. A wheel, containing a number of paired electrodes, was rolled along the windrow, and the average moisture or conductance was observed from a meter attached to the wheel. Whitten and Holaday (10) developed an electric meter for rapid measurement of moisture in cottonseed. This instrument is a hydraulic system to compress the cottonseed into a uniform sample for electrical conductance measurements. The authors suggest that this principle should work equally well with other agricultural products.

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[1] In cooperation with Texas Agricultural Experiment Station.

[2] Underscored figures in parentheses refer to items listed in References, page 13.

A number of commercial instruments using some of the principles described above are on the market today. Most of these were designed to measure the moisture of products other than hay, and then were adapted for hay. None of them provides for a relatively large sample and uniform arrangement of hay fibers.

The most widely recognized method for determining moisture in hay is by ovendrying known weights of hay and calculating moisture content from weight loss. This method is accurate but slow and cannot be used satisfactorily in the field.

METHODS AND INSTRUMENT DESIGN

Selection of a Method

A thorough search of manufacturers' literature was made in an attempt to find a moisture meter that would measure the moisture content of hay in the field rapidly and accurately. This search showed that the available instruments lack one or more of the following requirements: (1) accuracy, (2) speed, (3) relatively large representative sample, (4) portability, (5) adaptation for hay, and (6) low cost.

Preliminary experiments were conducted in an attempt to use the relative humidity approach for moisture measurements in hay. A number of factors presented problems with this method, such as: (1) Outside temperature and relative humidity affect the rate of rise in relative humidity in a sealed can of hay; (2) measurement of high-moisture hay was very inaccurate; (3) equilibrium relative humidity was reached too slowly; and (4) sample size affected the rate of rise in relative humidity.

An attempt to use light transmission techniques proved unsuccessful because of the inconsistent texture and density of the hay samples. Grinding the sample for more uniform transmission was regarded as impractical for field operations.

Electrical conductance and capacitance techniques were investigated also. Both methods are used successfully to measure moisture in grain (12). The capacitance method presented problems when applied to hay. It was very difficult to get the same amount of hay packed and orientated uniformly between the two parallel plates of the capacitor. The conductance method presented relatively simple problems of sample preparation and measurement and was selected for further investigation.

Electronic Circuit

The circuit consists of a transistor oscillator and amplifier combined with a differential Wheatstone bridge. The output of the oscillator is approximately 4 volts at 140 cycles per second and is applied across the bridge circuit. The output of the bridge is fed through two stages of amplification and rectified for measurement with a d.c. microammeter. The legs of the bridge are made up of a 10-turn, 100K ohms potentiometer with a readout microdial attached to its shaft, the measuring electrode, and a bank of adjustable resistors (screwdriver-adjustment type is desirable) that can be interchanged to alter the sensitivity or range. The bridge is balanced by adjusting the 10-turn potentiometer until a minimum reading is obtained on the microammeter.

The meter is protected from prolonged excessive current by a pushbutton switch so that the meter is out of the circuit except when a reading is being taken. The circuit is simple, draws very little current, requires no zeroing, and is very reliable. Drift in the transistors, caused by temperature or aging, has no effect on the reading of the bridge circuit. As the meter requires no warmup, it is always ready for immediate use. Nine-volt transistor radio batteries work very well for a power source. The complete circuit diagram is shown in figure 1.

The complete electrical circuit and controls can be compactly assembled into a sloping panel cabinet 8 by 8 1/16 by 8 inches. Convenient locations of components are as follows:

1. The panel meter in upper left-hand corner of sloping panel.

2. The 10-turn potentiometer and microdial in upper right-hand corner of sloping panel.

3. The pushbutton in lower left-hand corner and S-1 range switch in lower right-hand corner of sloping panel.

4. The power switch can be mounted in the lower right-hand corner of the vertical front panel.

5. The rest of the circuit can be mounted on a 7- by 7- by 2-inch chassis with the electrode wires coming into the rear of the chassis with a 2-conductor connector. Location of transistors and other electronic components is not critical.

6. The 11 screwdriver-adjustable potentiometers should be located on the chassis top for easy access and where they won't be disturbed once they are properly set.

Sample Holder and Press

The sample holder is a metal cylinder 5 inches in diameter by 6 inches tall with a removable bottom to facilitate removal of samples. This enables the use of 200 to 250 grams (dry matter) of hay.

Figures 2 and 3 show the detailed drawings for the hydraulic press, sample holder, and electrode plate. The electrode can be fastened to the plate shown in Detail A (figure 2) by machine screws. A 5- to 8-ton commercial hydraulic jack with a force gauge can be used for power.

Electrodes

Two types of electrodes are being used with the meter: (1) four pins equally spaced on a 1.41-inch radius, and (2) six pins equally spaced on a 2-inch radius. Sufficient tests have not been made with the six-pin electrode to evaluate its accuracy over the four-pin electrode, so it is not shown in drawings. The pins can be constructed of 1/4-inch stainless steel or brass with

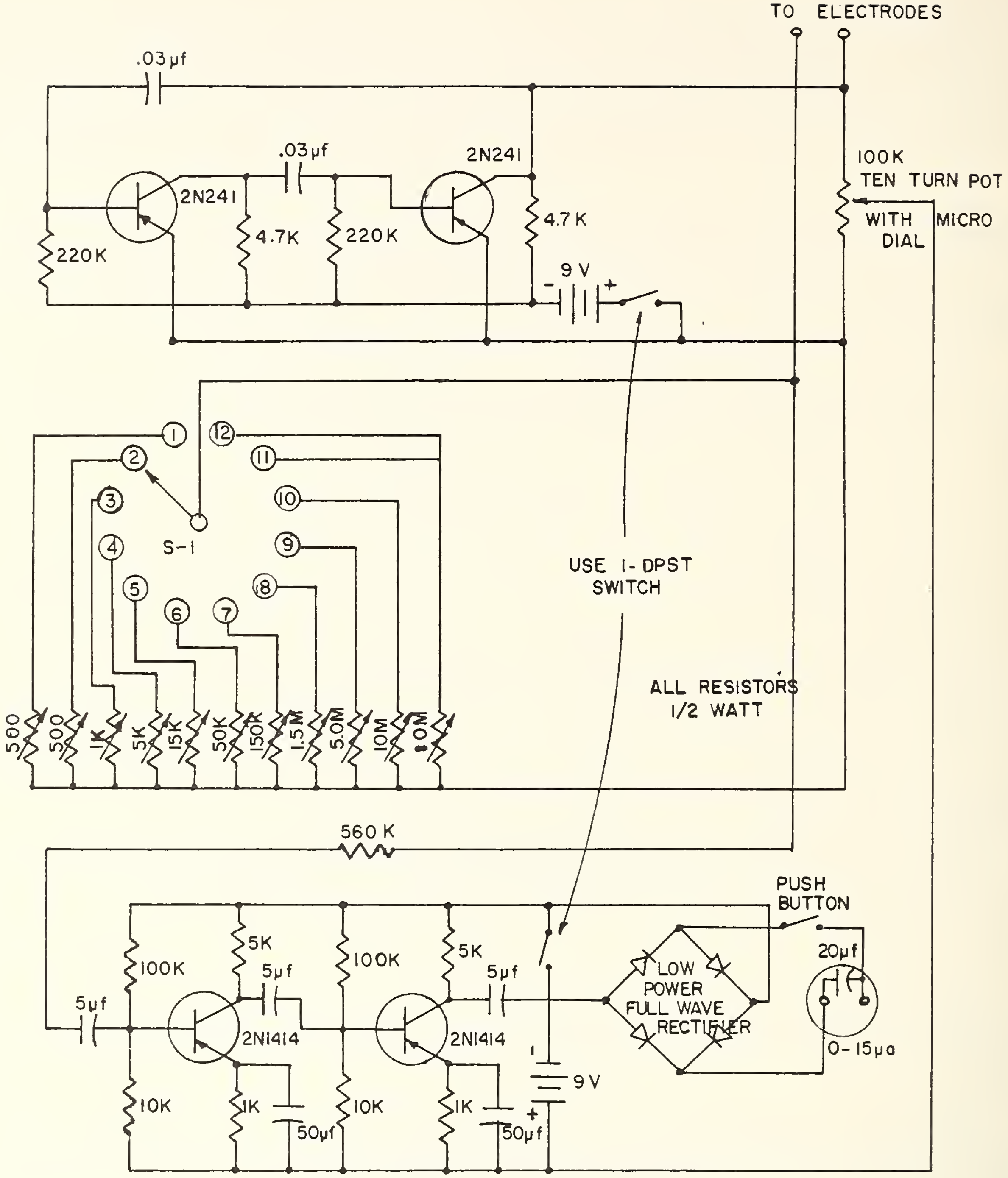

Figure 1. --Hay moisture meter circuit diagram.

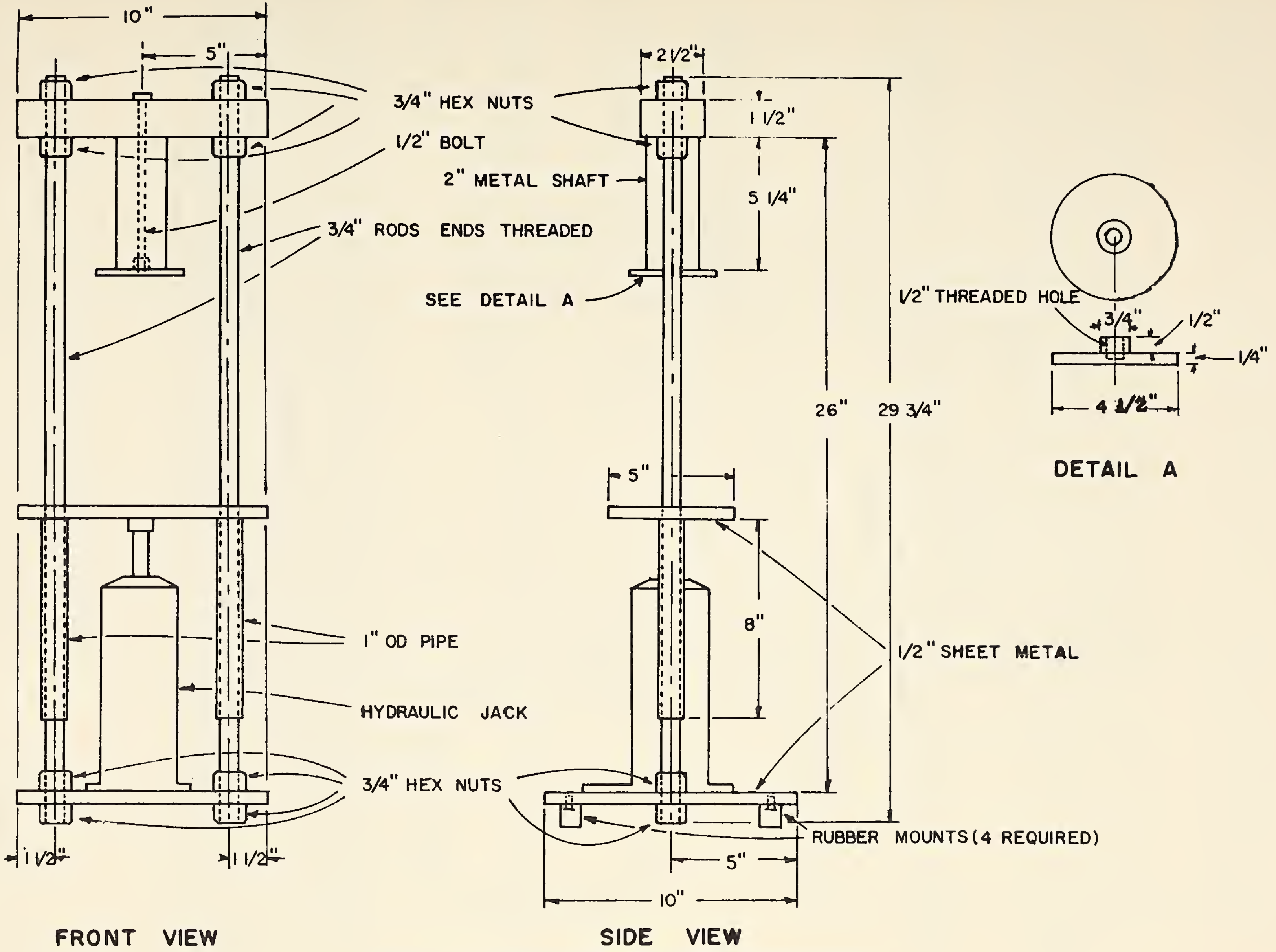

Figure 2. --Hydraulic press used with hay moisture meter.

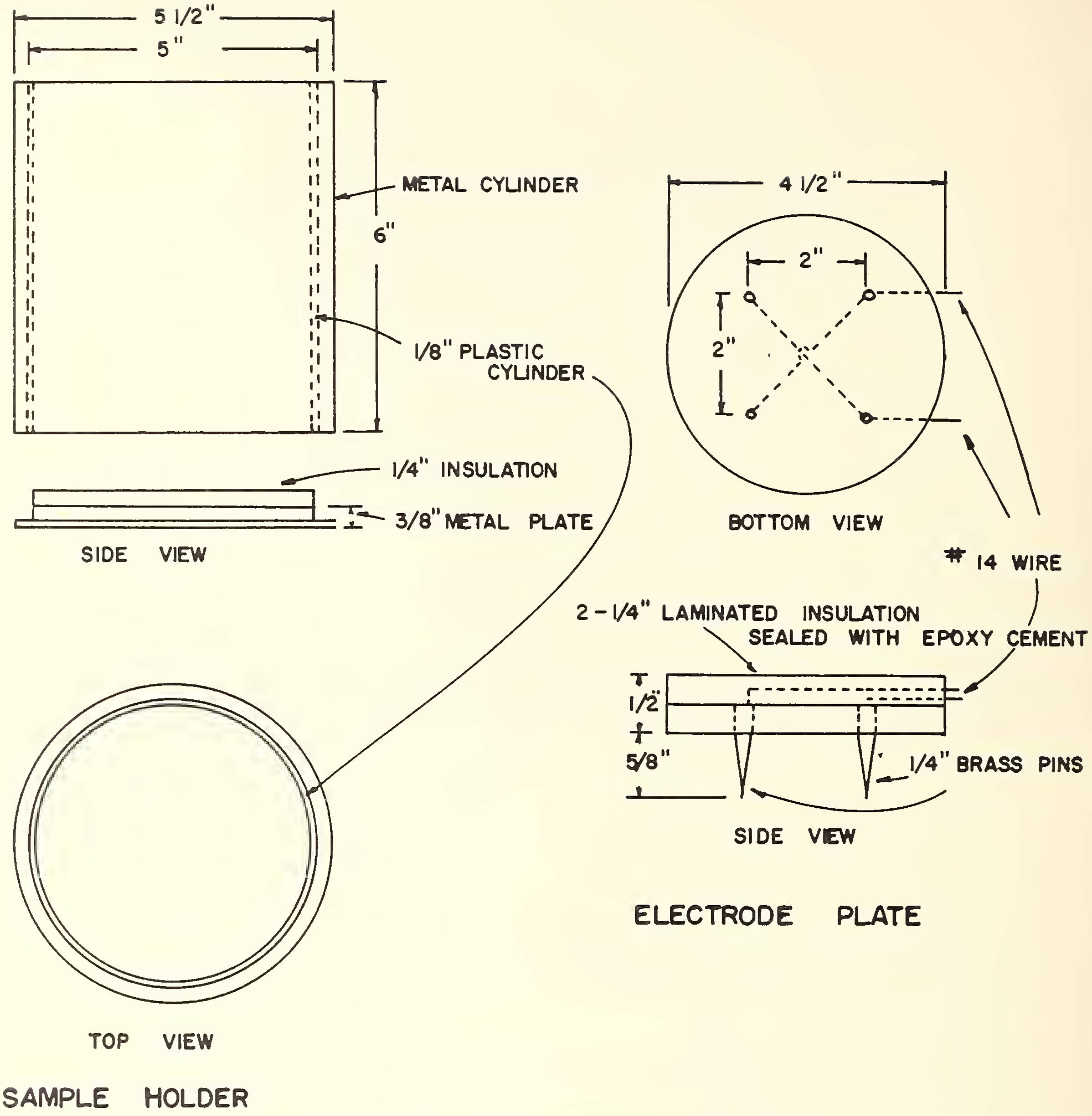

Figure 3.--Sample holder and electrode plate.

a 30° point. Flat, twin-lead, television antenna cable is recommended for attaching the electrode to the measuring instrument. It is very important to seal all pins and wires in the electrode with epoxy cement to prevent short circuits caused by moisture from the hay.

EXPERIMENTAL TRIALS

Laboratory Tests

Fresh-cut alfalfa hay was collected and brought into the laboratory. The hay was divided into 50 samples of approximately the same size. The samples were then air-dried to various levels of moisture to provide a range of moisture from 10 to 50 percent. The moisture content of each sample was measured by the compression device and then ovendried by the procedure outlined.

Simple correlations were made of moisture content determined by ovendrying vs. 10-turn potentiometer reading. As expected, when readings from the moisture meter were plotted against moisture content determined by the oven method, the relation was not linear for the entire range. For this particular experiment, the sensitivity of the moisture meter was adjusted so that the meter reading would be as linear as possible with moisture content ($r = 0.98$). Attempts to improve this correlation with quadratic regression were unsuccessful. A scatter diagram of the moisture reading vs. oven moisture is shown in figure 4.

Using the data and regression calculated above, the fixed resistors in the circuit bridge were adjusted so that each scale would be a step of 5-percent moisture. A reading of 50.0 on the potentiometer dial on the following scales would indicate the moisture shown for alfalfa hay:

When reading is 50.0 on potentiometer dial on--	Moisture content is--
	Percent
Scale 1	45
Scale 2	40
Scale 3	35
Scale 4	30
Scale 5	25
Scale 6	20
Scale 7	15

The calibration curves for each scale are shown in figure 5. The curves are calculated for a temperature of 75°F.

Field Test

To further test the hay moisture meter, an extensive field test was carried out. The meter was transported to a field where alfalfa had been cut for hay by the Texas Agricultural Experiment Station. As the hay dried, samples were drawn from the windrows and measured on the moisture meter in the manner described before. The samples were brought into the laboratory and ovendried for comparison. The results of these tests are shown in figure 6. The standard error of estimate for the hay moisture meter was ± 2.04 percent moisture, and $r = 0.94$. Figure 7 shows a picture of the hay moisture meter being used in the field.

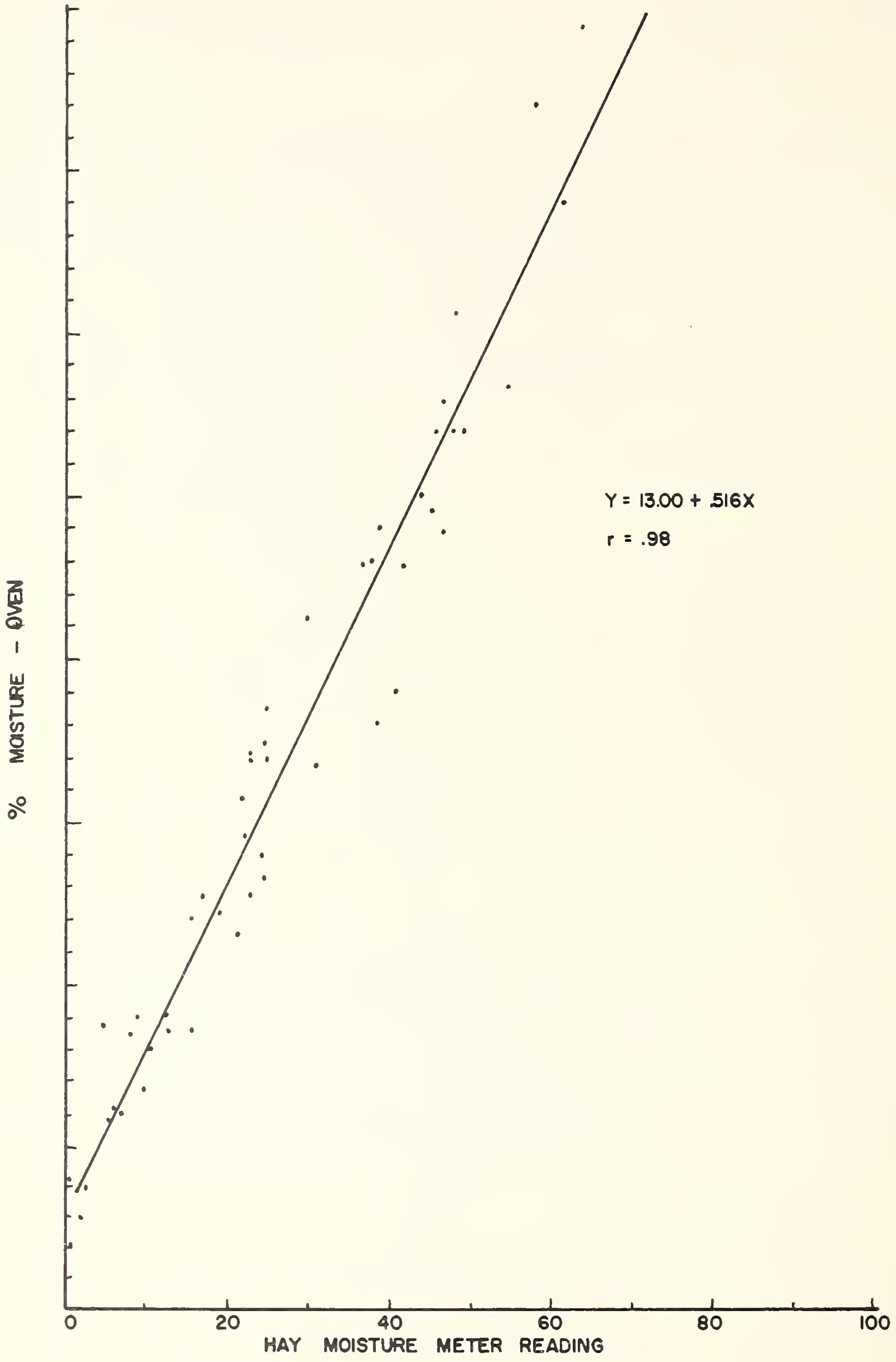

Figure 4. --Alfalfa lab test--moisture meter vs. oven.

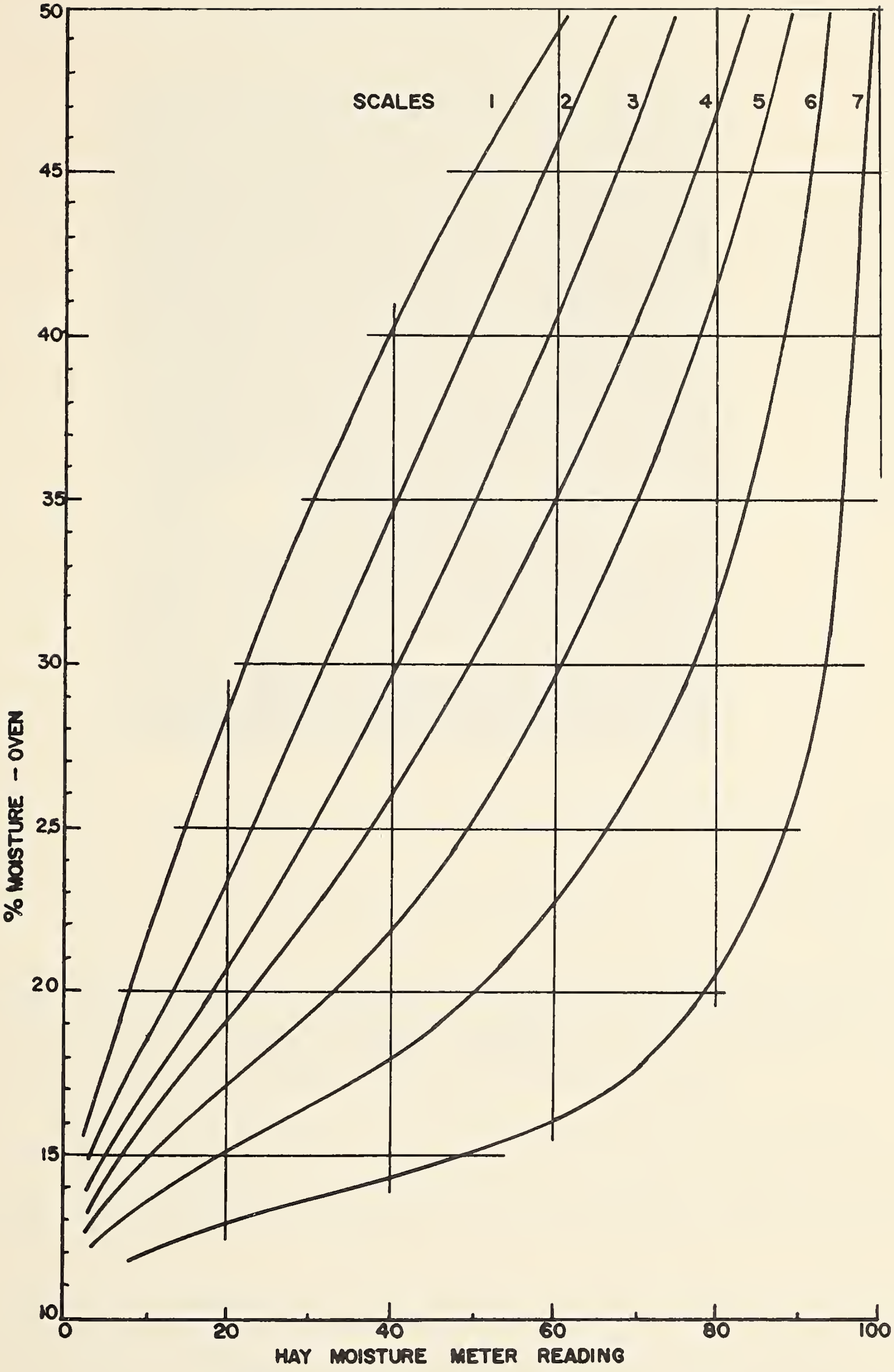

Figure 5. --Calibration curves--alfalfa.

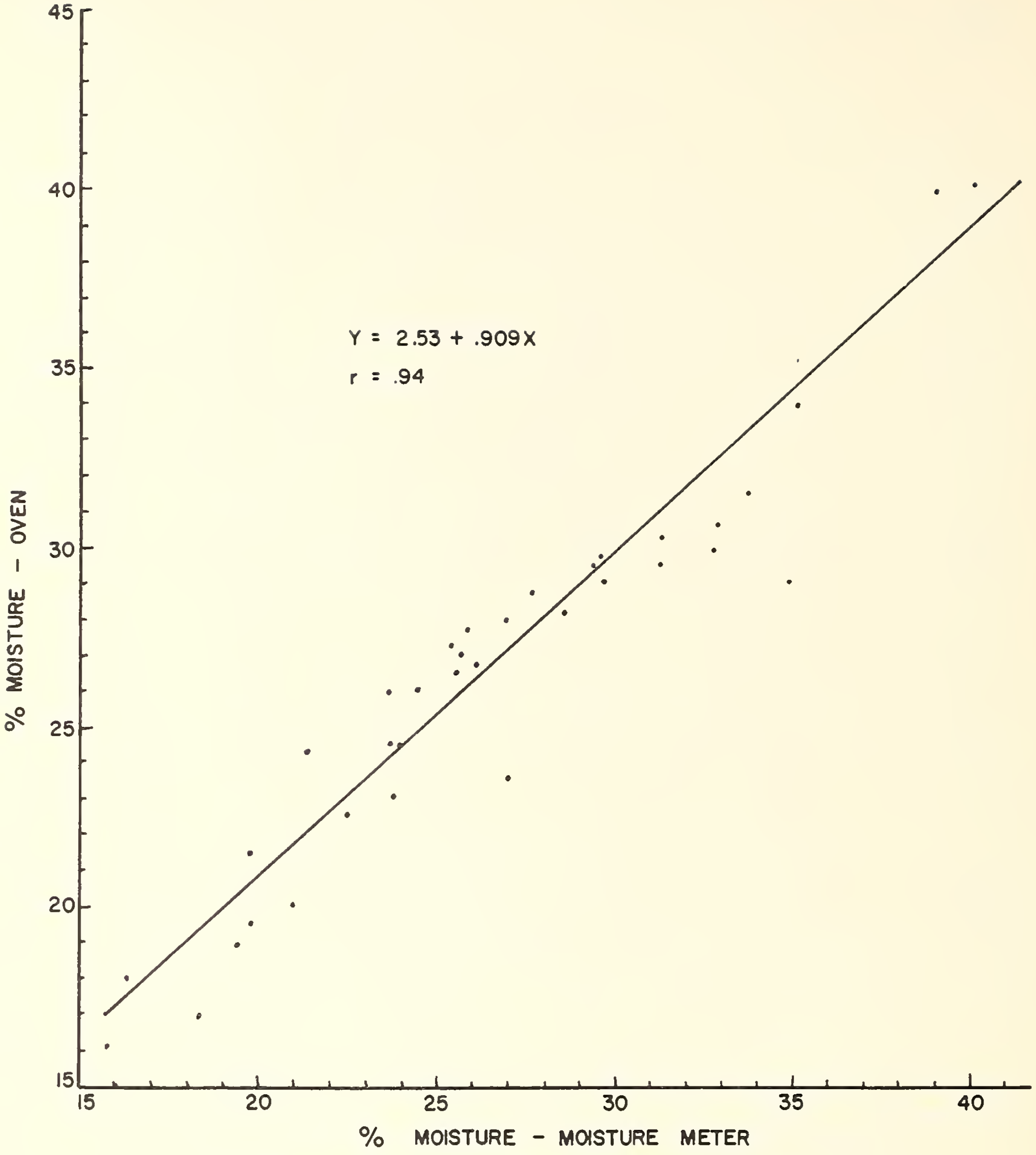

Figure 6. --Alfalfa field test--moisture meter vs. oven.

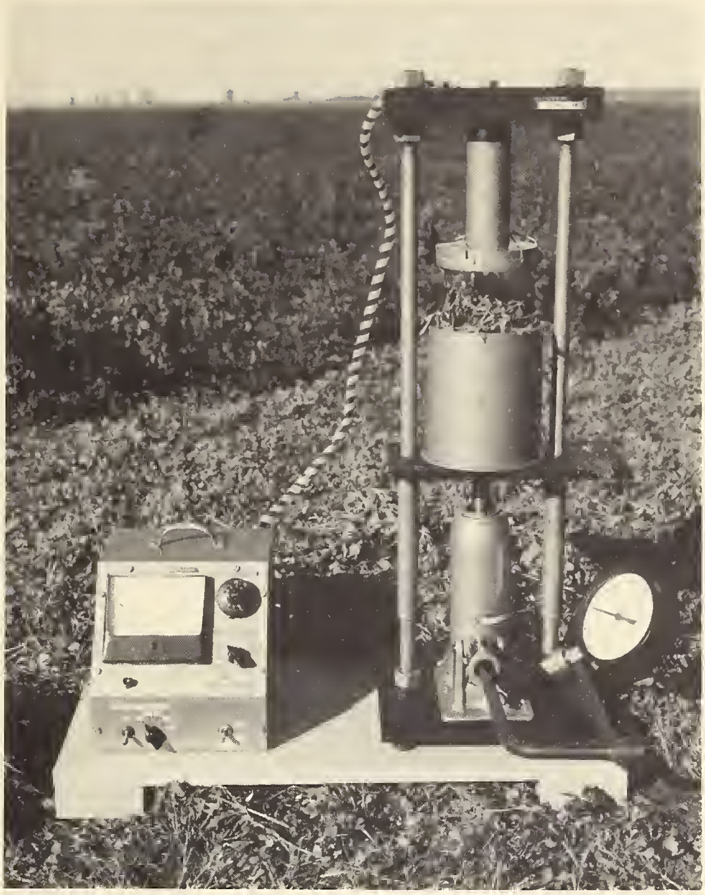

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Figure 7.--Hay moisture meter photographed during field tests.

CALIBRATION AND USE

For accurate calibration of the meter, hay moisture readings from the instrument must be compared with results of forced-air ovendrying since electrical components and the electrode will vary slightly from instrument to instrument. However, for preliminary calibration, the following procedure should be followed:

1. Adjust each of the potentiometers so that their entire resistance is in the circuit.

2. Short circuit the electrode. The 10-turn potentiometer dial should read 100.0 at all positions of switch S-1 when adjusted for minimum meter reading (minimum reading of meter will be zero in this instance).

3. Open circuit electrodes. The 10-turn potentiometer dial should read 0.0 at all positions of switch S-1 when adjusted for minimum meter reading except on scales 9, 10, and 11, which will probably read from 0 to 20.0 or 30.0 due to capacitance in the leads from the electrode and in the circuit. This presents no problem unless attempts are made to measure hay with moisture contents below 10 percent. If the meter is off scale during the entire rotation of the 10-turn potentiometer, the sensitivity of the meter is too high and can be reduced by placing an appropriate

resistance in parallel with the meter. If the 10-turn potentiometer dial reads something other than zero on the lower scales with open electrodes, the electrodes are not sufficiently insulated or other leakage is occurring.

4. Adjust the 11 potentiometers to proper resistance for moisture range desired.

(a) For calibration purposes, place a 4,000-ohm precision resistor across the electrodes.

(b) Set switch S-1 on scale 1.

(c) Turn the 10-turn potentiometer dial to 5.2.

(d) Adjust the 500-ohm potentiometer attached to position 1 of S-1 until a minimum meter reading is obtained. This will calibrate scale 1 so that a hay sample of 45 percent moisture will give a minimum reading on the meter when the 10-turn potentiometer dial is reading 50.0. The other scales can be calibrated in a similar manner:

When reading is 50.0 on potentiometer dial on--	Reading with 4K resistor	Moisture content Percent
Scale 1	5.2	45
Scale 2	7.5	40
Scale 3	11.5	35
Scale 4	16.0	30
Scale 5	23.0	25
Scale 6	39.0	20
Scale 7	71.5	15

Figure 5 shows the relation of 10-turn potentiometer dial reading and percent hay moisture after the scales have been calibrated. This calibration was for alfalfa hay at 75°F. As can be seen, the scales could be calibrated at closer intervals for direct reading of moisture content from meter to eliminate use of charts. Bear in mind that these are only approximate calibrations since each instrument will be slightly different unless constructed in the same shop.

Test Procedure

The following is the procedure used for measuring the moisture content with the hay moisture meter:

1. The 5-inch sample holder is filled by hand with as much hay as possible. It is necessary to fold the hay.

2. The sample and sample holder are placed under the compression electrode.

3. A pressure of 600 pounds per square inch (p.s.i.) is placed on the sample by the hydraulic jack. Wait 1 minute. The pressure on the hay will drift downward during the 1-minute waiting period. Bring the pressure back to 600 p.s.i. Be sure there is sufficient hay in the sample holder to prevent the electrode pins from completely penetrating the sample, as contact of the pins with the bottom of the holder would give an erroneous reading.

4. The meter is turned on and the 10-turn potentiometer is adjusted for a minimum reading on the microammeter. Record the reading on the 10-turn dial and the range used. Refer to the calibration chart for the actual moisture content of hay.

Other Factors Affecting Moisture Reading

Temperature.--Temperature affects the moisture reading at the rate of approximately 0.1 percent increase in indicated moisture per degree Fahrenheit increase in temperature.

Moisture Levels Above 50 Percent.--Application of 600 p.s.i. pressure to samples containing 50 percent or more moisture causes juices to be extracted. This causes the meter to give erratic readings that are meaningless. The electrode should be wiped clean after readings taken with high-moisture hay before making the next moisture test.

Varietal and Maturity Differences.--Variety and maturity differences in alfalfa did not reduce the accuracy of moisture meter significantly. Sudan and other grass hays were tested on a limited basis. These preliminary tests indicate that calibrations would have to be calculated for different types of hay.

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